RESEARCH PERSPECTIVES AT JEFFERSON LAB WITH THE 12 GEV UPGRADE

KEES DE JAGER

Jefferson Laboratory, 12000 Jefferson Avenue, Newport News, VA 23606, USA
E-mail: kees@jlab.org

The plans for upgrading the CEBAF accelerator at Jefferson Lab to 12 GeV are presented. The research program supporting that upgrade are illustrated with a few selected examples. The instrumentation under design to carry out that research program is discussed.

1 Introduction

The design parameters for the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility (JLab) were defined nearly two decades ago. In that period our understanding of the behaviour of strongly interacting matter has evolved significantly, providing important classes of experimental questions which can be optimally adressed by a CEBAF-type accelerator at higher energy. Fortunately, foresight in the design of the facility, coupled to technical developments, makes it feasible to triple the initial design value of CEBAF's beam energy to 12 GeV in a very cost-effective manner (about 15% of the cost of the initial facility).

The research program with the 12 GeV upgrade will provide breakthroughs in two key areas: 1) the experimental confirmation of the origin of quark confinement by QCD flux tubes and 2) the determination of the quark and gluon wave functions. In addition, the upgrade will provide important advances in areas already under study. A detailed overview of the upgrade research program is given in the White Paper[7].

2 Accelerator

CEBAF was originally designed to accelerate electrons to 4 GeV by recirculating the beam four times through two superconducting linacs, each producing an energy gain of 400 MeV per pass. Beam can be injected into the accelerator from either a thermionic or one of two polarized guns. In the polarized gun a strained GaAs cathode is illuminated by a 1497 MHz gain-switched diode laser. Each linac contains 20 cryomodules with a design accelerating gradient of 5 MV/m. Ongoing *in situ* processing has already resulted in an average gradient in excess of 7 MV/m, which has made it possible to acceler-

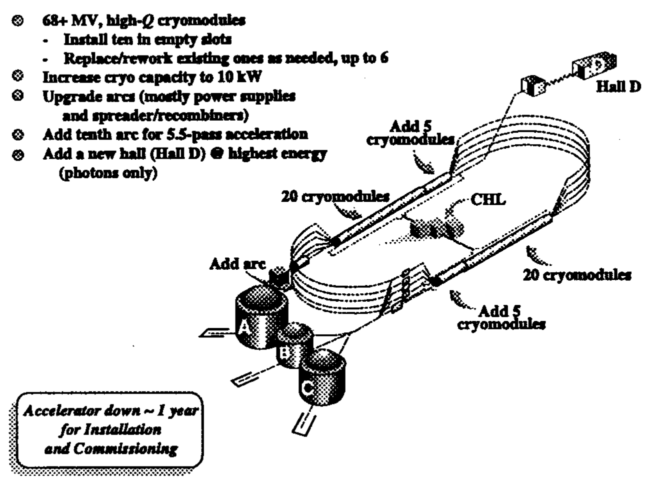

Figure 1. Overview of the accelerator upgrade to 12 GeV.

ate electrons to 5.7 GeV. The design maximum current is 200 μA CW, which can be split arbitrarily between three interleaved 499 MHz bunch trains. One such bunch train can be peeled off to any one of the Halls after each linac pass using RF separators and septa, while all Halls can simultaneously receive the maximum energy beam. Hall B with its large-acceptance detector CLAS requires a current as low as 1 nA, while a 100 μA beam is being delivered to one or even both of the other Halls.

Each linac tunnel provides sufficient space to install five additional newly designed cryomodules. The new cryomodules will each provide 68 MV (compared to the 28 MV from the existing ones), by increasing the gradient to 12.5 MV/m and the number of cavity cells from five to seven. By also replacing six of the existing ones the maximum energy gain per pass will be increased from 1.1 to 2.2 GeV, providing a maximum beam energy to Halls A, B and C of 11 GeV. Hall D will be provided with the desired maximum energy of 12 GeV by adding a tenth arc and recirculating the beam through one more linac. A total of 90 μA of CW beam can be provided at the maximum beam energy. Further modifications required are changing the dipoles in the final arcs from C-type to H-type magnets, replacing a large number of power supplies and doubling the central helium liquifier capacity to 10 kW. An overview of the upgrade of the accelerator is shown in fig. 1. It is expected that the installation activities will require six months, with an additional six months

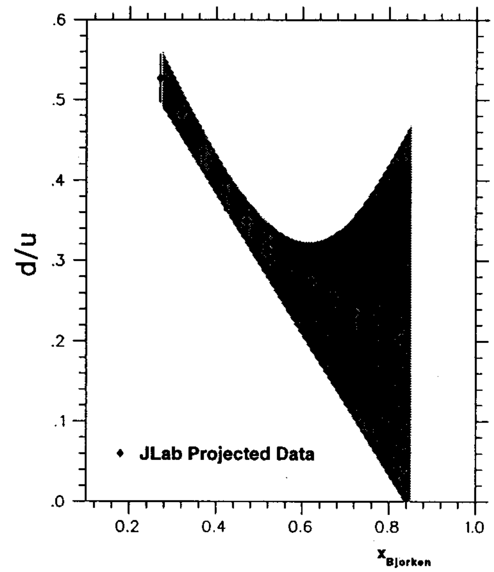

Figure 2. The ratio of the valence quark distributions as a function of x. The shaded band indicates the present uncertainty from existing data on F_2^d, the filled diamonds the expected data from the JLab $^3H/^3He$ DIS ratio measurement.

to fully commission the accelerator in its new configuration.

3 Hall A

The present base instrumentation in Hall A has been used with great success for experiments which require high luminosity and high resolution in momentum and/or angle of at least one of the reaction products. The central elements are the two High Resolution Spectrometers (HRS). Both of these devices have proven to provide a momentum resolution of better than 2×10^{-4} and an angular resolution of better than 1 mrad with a design maximum central momentum of 4 GeV/c.

With the 12 GeV upgrade (11 GeV for Halls A, B and C) a large kinematic domain becomes available for studies of deep inelastic scattering. The combination of high luminosity and high polarization of beam and targets will place Jefferson Lab in a unique position to make significant contributions to the understanding of nucleon and nuclear structure and of the strong

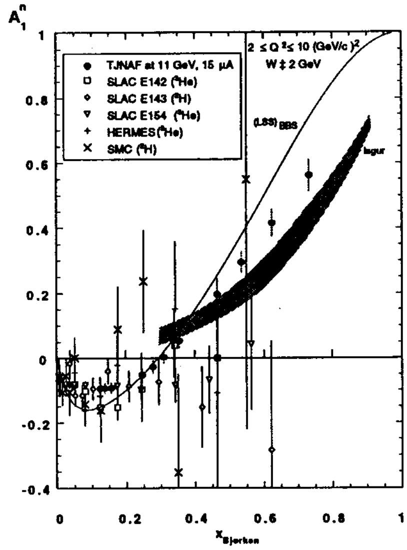

Figure 3. The neutron structure function A_1^n as a function of x. Shown are existing data (see explanation in figure) and data expected after the 12 GeV upgrade with the MAD spectrometer in Hall A. The solid curve represents the prediction of Leader *et al.*[4], the shaded band that of Isgur[5].

interaction in the high-x region.

The structure of the nucleon valence quark distributions is one of its fundamental properties. Precision data are scarce in this region (especially for the spin-dependent nucleon structure), due to the fact that the quark distribution drops rapidly when x becomes large. An overview of experiments considered in Hall A is given in ref. 2. Two of those are presented here in some detail.

In the first example[3] unpolarized inclusive electron scattering on ^3H and ^3He will provide precision measurements of the down quark to up quark ratio at high x. The present knowledge of this ratio, extracted from F_2 data on the deuteron, is severely hampered by the sizeable corrections for Fermi motion and binding effects. As shown in fig. 2, the proposed data will decrease the uncertainty in the d/u ratio by an order of magnitude at large x.

In the second experiment the spin structure functions g_1 and A_1 of the neutron will be measured accurately by using a polarized ^3He target. It will unambiguously establish the trend of A_1^n when x goes to 1, which will provide

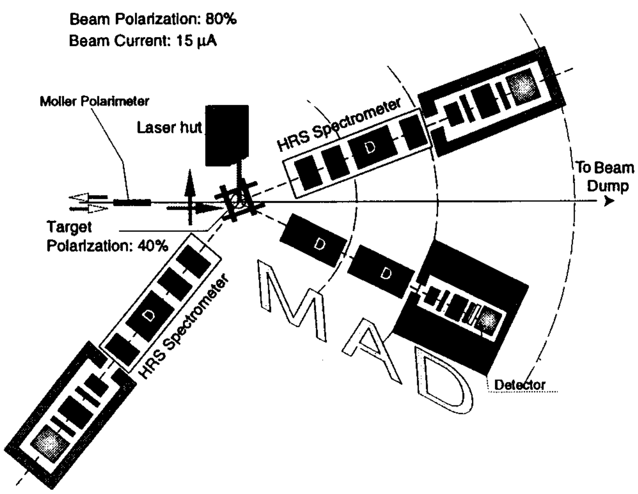

Figure 4. Lay-out of Hall A showing the configuration including the MAD spectrometer and the polarized ^{3}He target.

a benchmark test of pQCD and constituent quark models. Figure 3 clearly shows the limited existing data for A_1^n and the decisive quality of the proposed data. Equivalent measurements for the proton are also intended, as well as measurements of the g_2^n spin structure function and its moments. The latter measurements will provide a clean measure of a higher twist effect (twist 3), which is related to the quark-gluon interaction.

Three instrumentation upgrades are proposed to allow an optimal study of the intended experiments: a large acceptance spectrometer, an electromagnetic calorimeter and a ^{3}H target. The spectrometer would provide a tool for high-x studies of the properties of nucleons with an 11 GeV beam, where a large acceptance in both solid angle and momentum coupled to a moderate momentum resolution are needed. The availability of a high intensity 11 GeV beam will offer unique possibilities for studying both real and virtual Compton scattering. These experiments require the construction of a large, highly segmented, electromagnetic calorimeter. Other experiments besides Compton scattering will no doubt also benefit from such a detector.

The proposed MAD (Medium Acceptance Detector) device is a magnetic spectrometer built from two combined-function (quadrupole and dipole) superconducting magnets that can simultaneously produce a 1.5 T dipole field and a 4.5 T/m quadrupole field inside a warm bore of 120 cm. The quadrupole components provide the focussing necessary to achieve the desired solid angle while the dipole components provide the dispersion needed for momentum resolution. A magnetic design using TOSCA3D has been performed to establish the basic magnetic requirements and to provide 3D field maps for optics analysis. A two-sector $\cos(\phi)/\cos(2\phi)$ design with a low nominal current density has been selected and analyzed. Extra versatility can be achieved by varying the drift distance to the first magnet. Larger drift distances allow smaller scattering angles (down to 12°) at the cost of reduced acceptance. Optical properties and their impact on the performance have been studied, resulting in a momentum acceptance (resolution) of ± 15 (0.2)% and an angular acceptance (resolution) of 30 msr (2 mrad). The maximum central momentum is 6 GeV/c at a total bend angle of 20°, but can in priciple be increased by decreasing the bend angle.

The basic detector package for the MAD spectrometer will serve for most electron scattering experiments. The detectors have been designed to cover the full momentum and angular acceptance. The design includes an optional hadron configuration with a flexible particle identification system in the trigger and a very powerful PID in the off-line analysis. The main components of the basic detector package are: high resolution drift chambers, a hydrogen gas Čerenkov counter, trigger scintillator counters and a lead glass hadron rejector. The main components of the hadron configuration are: a variable pressure gas Čerenkov counter, two diffuse reflective aerogel counters and a Ring Imaging Čerenkov counter. A conceptual design for the MAD support structure has been completed. The device can be withdrawn up the truck ramp to allow operation with the existing HRS pair (see fig. 4).

A highly segmented total absorption calorimeter is proposed for use in high-luminosity Compton experiments at 11 GeV. The calorimeter must combine high spatial resolution, good energy resolution, fast time response, and be very radiation hard. The last point arises as the calorimeter will be placed as close as 10° to the beamline at luminosities of at least $10^{37}/\text{cm}^2/\text{s}$.

The requirements for EM calorimetry with 11 GeV beams have been set to accommodate deeply virtual Compton scattering (DVCS). Identification of the exclusive DVCS process requires a triple coincidence, with detection of the electron in a high resolution spectrometer and detection of the photon (proton) with high (modest) angular resolution. The optimal DVCS signal is obtained in a cone of approximately 100 mrad (half angle) around the $\vec{q}$-vector. Adding the spectrometer acceptance, a calorimeter angular acceptance of 60 msr is required.

The major considerations in the design of the tritium target are: minimize the amount of tritium, minimize the uncertainty in density, match the spectrometer acceptance, and maximize the luminosity. For safety considerations, the maximum amount of tritium should not exceed 30 kCi. Because of the ability to do coincidence experiments, the better match to the spectrometer solid angle, less stringent cooling requirements, and the more stable density as a function of current, a gas target is preferred, with a storage bed to remove the tritium from the target to a mechanically strong container for work on the target or for safety reasons. The major improvement required for the hall will be a tritium exhaust stack in order to vent the tritium out of the hall with sufficient height and speed to keep the exposure at ground level to an acceptable level.

4 Hall B

The primary mission of the CEBAF Large Acceptance Spectrometer (CLAS) in Hall B is to carry out experiments that require the detection of several, only loosely correlated particles in the hadronic final state at a limited luminosity. CLAS is a magnetic toroidal multi-gap spectrometer. Its magnetic field is generated by six superconducting coils. The detection system consists of drift chambers to determine the track of a charged particle, gas Čerenkov counters for particle identification, scintillation counters for the trigger and for measuring time-of-flight and electromagnetic calorimeters to detect showering particles like electrons and photons. CLAS has typically operated at an electron beam luminosity of 10^{34} cm^{-2}s^{-1}, while tagged photon experiments were carried out at around 10^7 photons/s.

With the 12 GeV upgrade the CLAS research program will focus on Generalized Parton Distributions (GPD) through the study of exclusive processes at large momentum transfer. The GPD's can be considered as overlap integrals between different components of the hadronic wave function[6], governed by the selection of the final state. Measurements of these GPD's will thus make it possible to map out quark and gluon wave functions. For example, the distribution of angular momentum among nucleon constituents can only be accessed through GPD's. Factorization is an essential ingredient in the extraction of GPD's. For Deeply Virtual Compton Scattering (DVCS) one expects scaling to have been achieved at 12 GeV, but this is not clear for other processes.

The CLAS upgrade incorporates two major improvements: 1) increasing the luminosity by an order of magnitude to account for the lower cross section values, 2) provide more complete detection of the hadronic final state. The use of major components (torus magnet, scintillators, Cerenkov counters and EM calorimeters) will be retained. The tracking chambers will be replaced

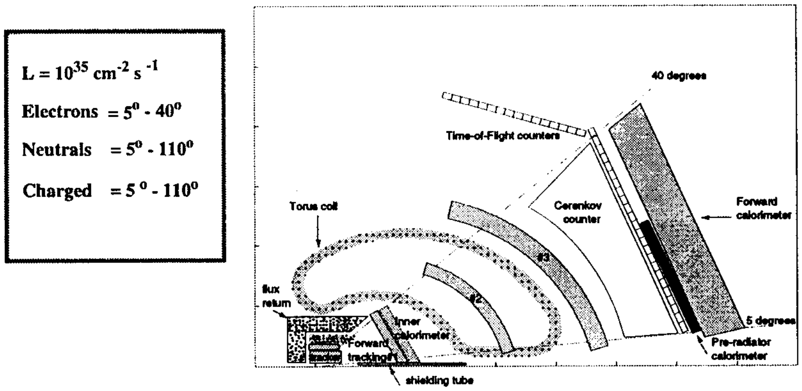

Figure 5. Overview of the upgrades proposed for the CLAS detector.

and a new central detector added. A conceptual design of the upgrade is shown in fig. 5.

5 Hall C

The Hall C facility has generally been used for experiments which require high luminosity and moderate resolution. The core spectrometers are the High Momentum Spectrometer HMS and the Short Orbit Spectrometer (SOS). These two devices have been used flexibly as either electron or hadron arms, at times in coincidence with each other, at times in coincidence with a third experiment-specific arm. The HMS has a maximum momentum of 7.6 GeV/c, the SOS a value limited to only 1.7 GeV/c.

The Hall C research program after the 12 GeV upgrade will be focused on electron-hadron coincidence experiments at large $z \equiv E_{h/\nu}$, where E_h and ν are the hadron energy and the energy loss, respectively. Examples of such experiments are measurements of the pion form factor at large Q^2 and of duality. The former will provide important insights in soft scattering contributions, such as gluonic effects, to the form factor of this lightest hadron. Quark-hadron duality was first observed[7] as a global scaling curve for the F_2 structure function, but has recently been revisited through new high-precision resonance data[8]. Confirmation of duality in spin structure functions and in fragmentation would open up studies of the spin and flavour decomposition of quark distributions with an unprecedented accuracy.

This research program requires particle detection at a high luminosity,

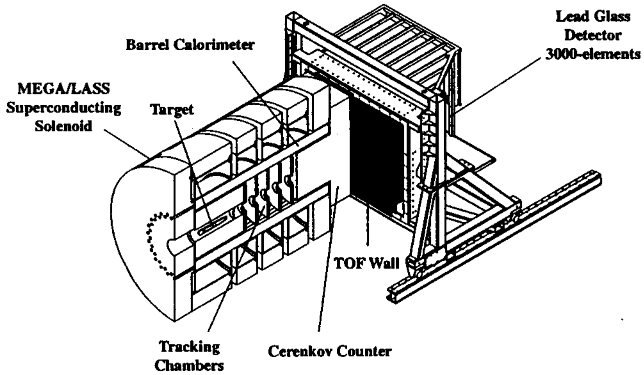

Figure 6. Schematic view of the detector in Hall D.

a small minimum scattering angle and a high maximum momentum. These conditions will be met by the so-called Super High Momentum Spectrometer (SHMS) which will replace the SOS spectrometer. The SHMS design consists of two super-conducting quadrupoles and one combined-function magnet, similar to those used in the MAD spectrometer in Hall A. It will have a maximum momentum of 11 GeV/c, a minimum scattering angle of 5.5°, a momentum acceptance (resolution) of ± 10 (0.2)% and an angular acceptance (resolution) of 2 msr (2 mrad). The basic configuration of the detector stack would consist of DC tracking chambers, trigger scintillator hodoscopes and a lead glass calorimeter. Other detectors can be added as experiments require.

6 Hall D

The Hall D research program will be focused on a definitive measurement of the spectrum of exotic hybrid mesons, which are expected in an energy range from 1 to 2.5 GeV. The observation of such direct manifestations of gluonic degrees of freedom will provide understanding of confinement[9]. These excitations can be probed far more effectively with photons than with $\pi-$ or K-mesons, because the quark spins are aligned in the virtual vector mesons. Several exotic hybrid excitations can be uniquely identified through their J^{PC} quantum numbers, which can be determined by a full partial-wave analysis of excitations by linearly polarized photons. The optimum photon energy for production of exotic hybrids is between 8 and 9 GeV, if one also requires a good momentum resolution over the full energy range of interest. Linearly polarized photons in this energy range are optimally produced by coherent bremsstrahlung. A tagging system will allow to measure the photon energy to within 0.1%. The Hall D detector provides a nearly hermetic acceptance for both charged and neutral particles and includes several particle identification systems to yield a very good K-π separation. Figure 6 is a schematic representation of the proposed detector. Momentum analysis of charged particles is achieved with a super-conducting solenoid and tracking chambers.

7 Summary

The proposed upgrade of the JLab facility to 12 GeV has been described, including the instrumentation under design in the three existing halls and in the proposed additional Hall D. The research program will be focused on the experimental verification of QCD confinement and a determination of the wave functions of the nucleon constituents.

Acknowledgments

This work was supported by DOE contract DE-AC05-84ER40150 under which the Southeastern Universities Research Association (SURA) operates the Thomas Jefferson National Accelerator Facility.

References

1. The 12 GeV Upgrade of CEBAF, White Paper prepared for the NSAC Long Range Planning Exercise, 2000, L.S. Cardman *et al.*, editors.
2. Proceedings of the HiX2000 workshop, March 2000, Temple University, Philadelphia, J.P. Chen and Z.E. Meziani, editors.
3. I.R. Afnan *et al.*, nucl-th/0006003, to be published in *Phys. Rev. C.*
4. E. Leader, A. V. Sidorov and D. B. Stamenov, *Phys. Lett.* B **488**, 283 (2000).
5. N. Isgur, *Phys. Rev.* D **59**, 034013 (1999).
6. X. Ji, *Phys. Rev. Lett.* **78**, 610 (1997); A. Radyushkin, *Phys. Lett.* B **380**, 417 (1996).
7. E.D. Bloom and F.J. Gilman, *Phys. Rev. Lett.* **16**, 1140 (1970).
8. R. Ent, C.E. Keppel and I. Niculescu, *Phys. Rev.* D **62**, 073008 (2000).
9. N. Isgur, R. Kokoski and J. Paton, *Phys. Rev. Lett.* **54**, 869 (1985); S. Godfrey and J. Napolitano, *Rev. Mod. Phys.* **71**, 1411 (1999).